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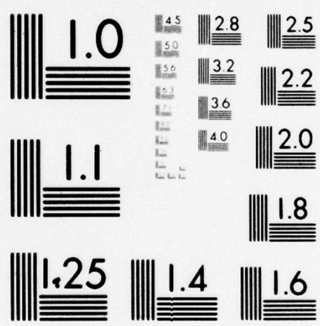

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

CALCULATION OF STREAMLINES ON THE USNS VANGUARD

BY

H. T. Wang
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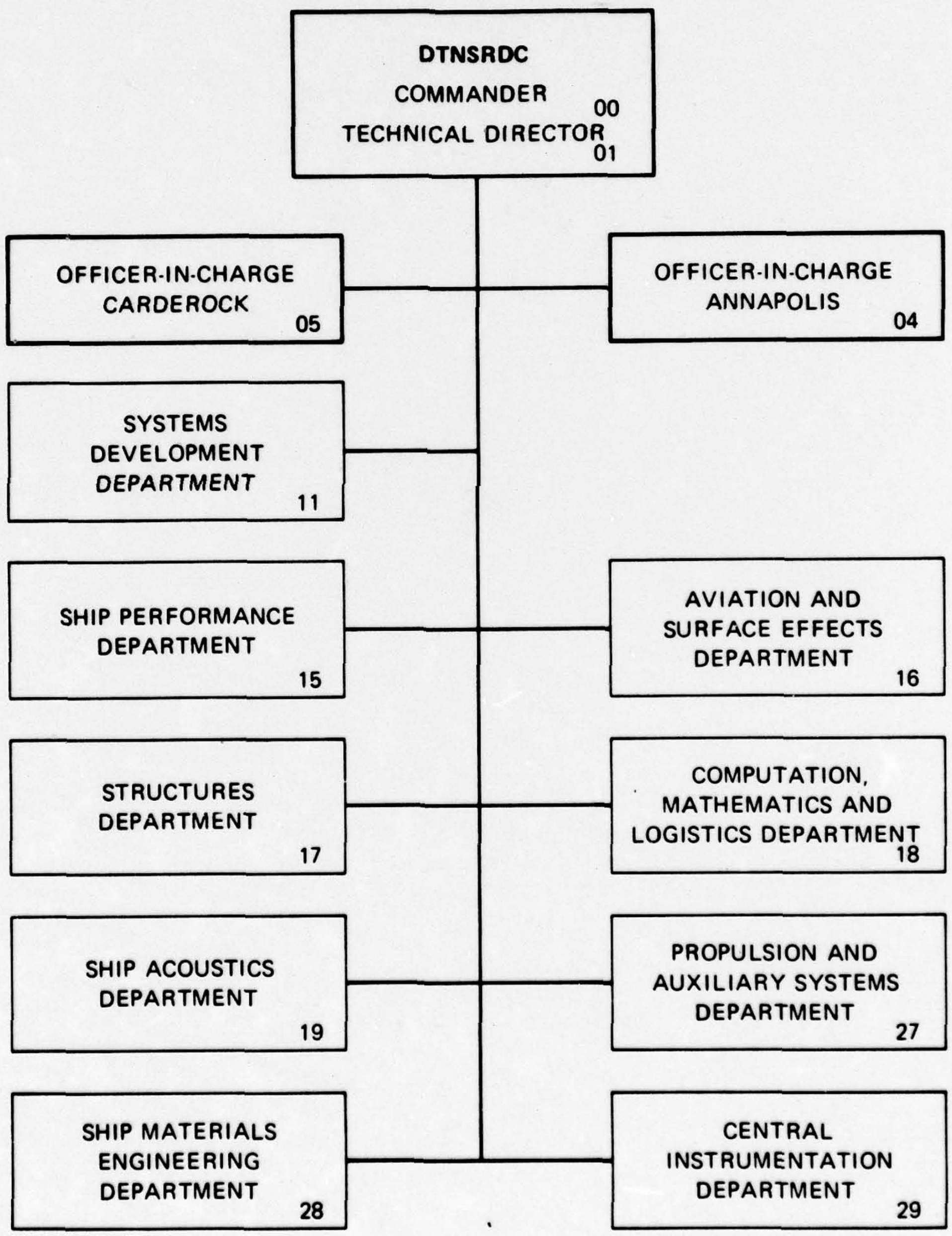
SHIP PERFORMANCE DEPARTMENT
DEPARTMENTAL REPORT

September 1979 DTNSRDC/SPD-0899-01

CALCULATION OF STREAMLINES ON THE USNS VANGUARD DTNSRDC/SPD-0899-01

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
14 DTNSRDC/SPD-0899-01

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 Calculation of Streamlines on the USNS VANGUARD.

5. TYPE OF REPORT & PERIOD COVERED
9 Final report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 H. T. Wang [redacted] J. Libby

8. CONTRACT OR GRANT NUMBER(s)
P.O. ~~R-~~184803

9. PERFORMING ORGANIZATION NAME AND ADDRESS
David W. Taylor Naval Ship R&D Center
Bethesda, Maryland 20084

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
1552-123

11. CONTROLLING OFFICE NAME AND ADDRESS
Sperry Rand Corporation
Sperry Marine Systems
Great Neck, NY 11020

12. REPORT DATE
11 Sept[redacted]79

13. NUMBER OF PAGES
~~25~~ 12 27

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Calculation of Streamlines
Surface Ship
Free Surface
Double Model

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
Computer calculations were made of the paths of streamlines on the hull of the USNS VANGUARD (TAGM-19). The calculations were made by using a potential flow computer program which accounts for free surface effects. Computer runs were made for ship speeds of 0, 5, 10, 20, and 30 knots, where the 0-knot speed corresponds to the double model case where the free surface is treated as a plane of symmetry. Numerous computer-generated figures of the ship lines and streamlines for the 0-, 5-, and 10-knot cases are presented. The results are — Over

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also summarized in tabular form. For a streamline passing through a fixed point on the bottom of the hull at Frame 143, the axial location of a proposed acoustic receiver array, the results show that the closest approach of the streamline to the actual free surface monotonically increases with increasing speed. Thus, the 0-speed case represents the most conservative estimate. The results also show that streamlines located 7.5 feet (2.3 m) outboard of the vertical plane of symmetry, the outreach of the proposed receiver array, approach no closer than 11 feet (3.4 m) to the free surface in the bow region for the 0-, 5-, and 10-knot cases.

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ABSTRACT

Computer calculations were made of the paths of streamlines on the hull of the USNS VANGUARD (TAGM-19). The calculations were made by using a potential flow computer program which accounts for free surface effects. Computer runs were made for ship speeds of 0, 5, 10, 20, and 30 knots, where the 0-knot speed corresponds to the double model case where the free surface is treated as a plane of symmetry. Numerous computer-generated figures of the ship lines and streamlines for the 0-, 5-, and 10-knot cases are presented. The results are also summarized in tabular form. For a streamline passing through a fixed point on the bottom of the hull at Frame 143, the axial location of a proposed acoustic receiver array, the results show that the closest approach of the streamline to the actual free surface monotonically increases with increasing speed. Thus, the 0-speed case represents the most conservative estimate. The results also show that streamlines located 7.5 feet (2.3 m) outboard of the vertical plane of symmetry, the outreach of the proposed receiver array, approach no closer than 11 feet (3.4 m) to the free surface in the bow region for the 0-, 5-, and 10-knot cases.

ADMINISTRATIVE INFORMATION

This work was sponsored by Sperry Systems Management of the Sperry Rand Corporation under Purchase Order P-184803 dated 13 February 1979. The work was performed under internal Work Unit 1552-123. no PE no

INTRODUCTION

Sperry Systems Management of the Sperry Rand Corporation requested the David W. Taylor Naval Ship R&D Center (DTNSRDC) to calculate the paths of streamlines on the hull of the USNS VANGUARD (TAGM-19) to serve as an indication of the paths of bubbles entrained by bow phenomena such as the bow wave breaking, deaeration, and possible cavitation at high speeds on rough hull surfaces. The assumption of bubbles following the paths of streamlines decreases in validity with increasing bubble size. As bubble size increases, the bubbles tend to cross streamlines due to buoyancy and streamline curvature effects, which are proportional to the cube of bubble radius. The actual intensity and distribution of bubble sizes arising from the various entrainment phenomena is beyond the scope of the present work.

The particular concern was that some of the bubbles would pass through the neighborhood of an acoustic receiver array located on the bottom of the hull at Frame 143 which is 213.9 ft (65.19 m) aft of the forward perpendicular. The receiver array extends 7.5 ft (2.3 m) outboard of the vertical plane of symmetry on each side of the keel. The USNS VANGUARD has a length of 575.225 ft (175.32 m) at the 25-ft (7.62 m) Design Waterline (DWL) and a beam of 75 ft (22.86 m). The forward 75.13 ft (22.90 m) and aft 118.88 ft (36.23 m) of length are identical to those for a T2 Tanker. The amidships region is somewhat longer and wider than that for a T2 Tanker.

The calculations were made by using the XYZ Free Surface Program. It is a potential flow program which accounts for free-surface effects and was previously used to compute streamlines on the USNS DUTTON.[1*] The theory underlying the program is briefly described here and in more detail in References 1 and 2. The velocity field is written in terms of a sum of sources placed over a series of quadrilaterals which are used to model the surface of the ship and a limited region of the undisturbed free surface. The source densities are determined by the condition of no flow through the surface of the ship and a linearized condition on the free surface.

The hull of the ship was modeled by 144 quadrilaterals, as in Reference 1. Figure 1 shows the side, bottom, and front views of the M- and N-Lines, which determine the vertices of the quadrilaterals.[**] With the exception of the bow and stern regions, the M-Lines are nearly parallel to the longitudinal X-axis while the N-Lines are nearly perpendicular to the X-axis. The jagged appearance of the quadrilaterals is due to the sweep of the M-and N-Lines in the bow and stern regions. This was done largely to minimize the difference in dimensions of neighboring quadrilaterals in these regions. Figure 1 also shows that the origin of the coordinate system used is at the forward perpendicular. The free surface was modeled by 272 quadrilaterals. It is estimated that this arrangement will give streamline patterns which are accurate to within 1 foot (0.3 m).

* Complete listing of references is given on page 8.
** This follows the terminology given in Reference 2.

Calculations were made for ship speeds of 0, 5, 10, 20, and 30 knots, with corresponding Froude numbers F_n of 0, 0.062, 0.124, 0.248, and 0.372, where F_n is given by

$$F_n = \frac{U}{\sqrt{gL}} \tag{1}$$

where U is the ship speed,

g is the gravity constant = 32.2 ft/sec^2 (9.8 m/sec^2),

L is the length of the DWL = 575.225 ft (175.32 m).

The 0-knot speed corresponds to the double model case where the free surface is treated as a plane of symmetry.

While the Purchase Order specified computer runs for only 0, 5, and 10 knots, runs were also made for 20 and 30 knots to give a clearer indication of the effect of higher Froude numbers on the streamlines. As shown in the following section, there is relatively little change in the streamline paths for the low Froude numbers corresponding to 0, 5, and 10 knots.

PRESENTATION OF RESULTS

Since the principal interest centers on the acoustic receiver array located at Frame 143, which corresponds to X = -213.9 ft (-65.19 m), streamlines through fixed points on the surface of the hull at Frame 143 were traced to the bow and stern. The slope of a

given streamline changed each time it entered a new quadrilateral element. The slope was determined by the ratio of the calculated velocities at the center of the given quadrilateral and the two neighboring quadrilaterals above and to the right. Table 1 lists 22 streamlines that were traced for the 0-, 5-, 10-, 20-, and 30-knot cases. The streamlines at Frame 143 range from Streamline 1, which is 0.1 ft (0.03 m) away from the keel, to Streamline 22, which is 0.75 ft (0.23 m) below the free surface. For each streamline, Table 1 shows the point of closest approach to the actual ocean surface, which includes the bow wave, in the bow region. To give an indication of the bow wave, Table 2 gives the elevation of the bow wave over the forward 100 ft (30.5 m) of the ship.

In order to give an indication of the streamline pattern for other possible locations of the acoustic receiver array, forward and aft of Frame 143, Table 3 shows the values of Y and Z for the 22 streamlines at X = -155 ft (-47.24 m) and X = -244 ft (-74.37 m) for the 0-knot case. The values of Y and Z for the 5- and 10-knot cases differ by less than 0.1 ft (0.03 m) from the values for the 0-knot case. Thus, the values shown in Table 3 are applicable to all 3 speeds to within 0.1 ft (0.03 m).

Figure 2 shows side, bottom, and front views of the streamlines and ship N-Lines for the 0-knot or double model case. In this figure and all subsequent figures, the bow is to the right. Figures 3 and 4 respectively show side and bottom views of the forward and rear halves

of the streamlines and ship N-Lines. Figures 5 through 7 and 8 through 10 show corresponding results for the 5- and 10-knot cases, respectively.

DISCUSSION OF RESULTS

Table 1 shows that the difference in the closest approach to the actual free surface between the 0-, 5-, and 10-knot cases is less than 2.4 ft (0.73 m) for all the streamlines.

As indicated in Table 1 and also shown in Figures 2 through 10, the most outboard (higher numbered) streamlines, which start nearest to the free surface, are not traced all the way to the bow and stern. The XYZ Free Surface Program stops the calculation of the streamlines when they reach the undisturbed free surface (Z = 0). At present, the program computes velocities only on quadrilateral elements, which do not extend above Z = 0. However, the program does compute the elevation of the free surface.

The results of Table 1 may be used to determine the furthest outboard location of the acoustic receiver array at Frame 143 for a given value of the closest approach to the actual free surface. For example, for a closest approach of 7 ft (2.13 m), the array may be located up to about 17 ft (5.49 m) outboard of the keel at Frame 143 (Streamline 12) for speeds between 0 and 10 knots. For the 7.5-ft (2.3 m) outreach of the proposed receiver array, Table 1 indicates that the streamlines have a closest approach of approximately 11 ft (3.4 m) for speeds between 0 and 10 knots.

Table 1 shows that the closest approach to the free surface monotonically increases with increasing speed. This is largely due to the increase in height of the bow wave with speed, as shown in Table 2, which also shows that the crest moves aft with increasing speed.

Table 3 shows that there is relatively little difference in the locations of the streamlines between a forward location at X = -155 ft (-47.24 m) and at an aft location X = -244 ft (-74.37 m) for speeds between 0 and 10 knots. This means that the furthest outboard locations of the acoustic array at Frame 143 determined from Table 1 for permissible values of closest approach essentially apply for 155 ft (47.24 m) $\leq |X| \leq$ 244 ft (74.37 m).

Figures 2 through 4 and 9 through 10 show that the streamlines for the 0- and 10-knot cases are relatively smooth. Figures 5 through 7 show that the streamlines for the 5-knot case are jagged. This is due to the decrease in wavelength of the bow wave when compared to a speed of 10 knots, thus requiring more quadrilaterals for accurate modeling of the bow wave. This problem is avoided in the 0-knot or double model case, since the free surface is considered to be a plane of symmetry. Thus, it appears to be adequate to calculate the paths of streamline for low speed cases with Froude numbers below about 0.12 (a ship speed of about 10 knots in the present case) as double model cases. Table 1 shows that the maximum error in values for closest approach to the free surface computed for the double model would be about 2 feet (0.61 m). The exact height of the bow wave, of course, can only be obtained by considering free surface effects. The computer cost for the free surface case is approximately five times more than the double model case.

CONCLUSION

The report has presented a detailed calculation of the paths of streamlines on the hull of the USNS VANGUARD (TAGM-19). Assuming that bubbles follow the streamlines, the closest approach of the streamlines passing through the region of the proposed receiver array, located at Frame 143 with an outreach of 7.5 feet (2.3 m), is approximately 11 feet (3.4 m) from the free surface in the bow region. This appears to be adequate clearance to ensure that bubbles entrained on the surface near the bow do not pass through the receiver array.

ACKNOWLEDGMENT

The authors wish to thank Mr. Charles W. Dawson with whom they had a number of helpful discussions concerning the use of the computer program. They also wish to thank Ms. Deborah A. Johnson who helped to generate the quadrilateral representation of the ship.

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1. Wang, H.T., C.W. Dawson, and N.M. White, "Calculation of Streamlines on the USNS DUTTON," DTNSRDC Report SPD-771-01 (May 1977).

2. Dawson, C.W., "A Practical Computer Method for Solving Ship-Wave Problems," Second International Conference on Numerical Ship Hydrodynamics (Sep 1977), pp. 30-38.

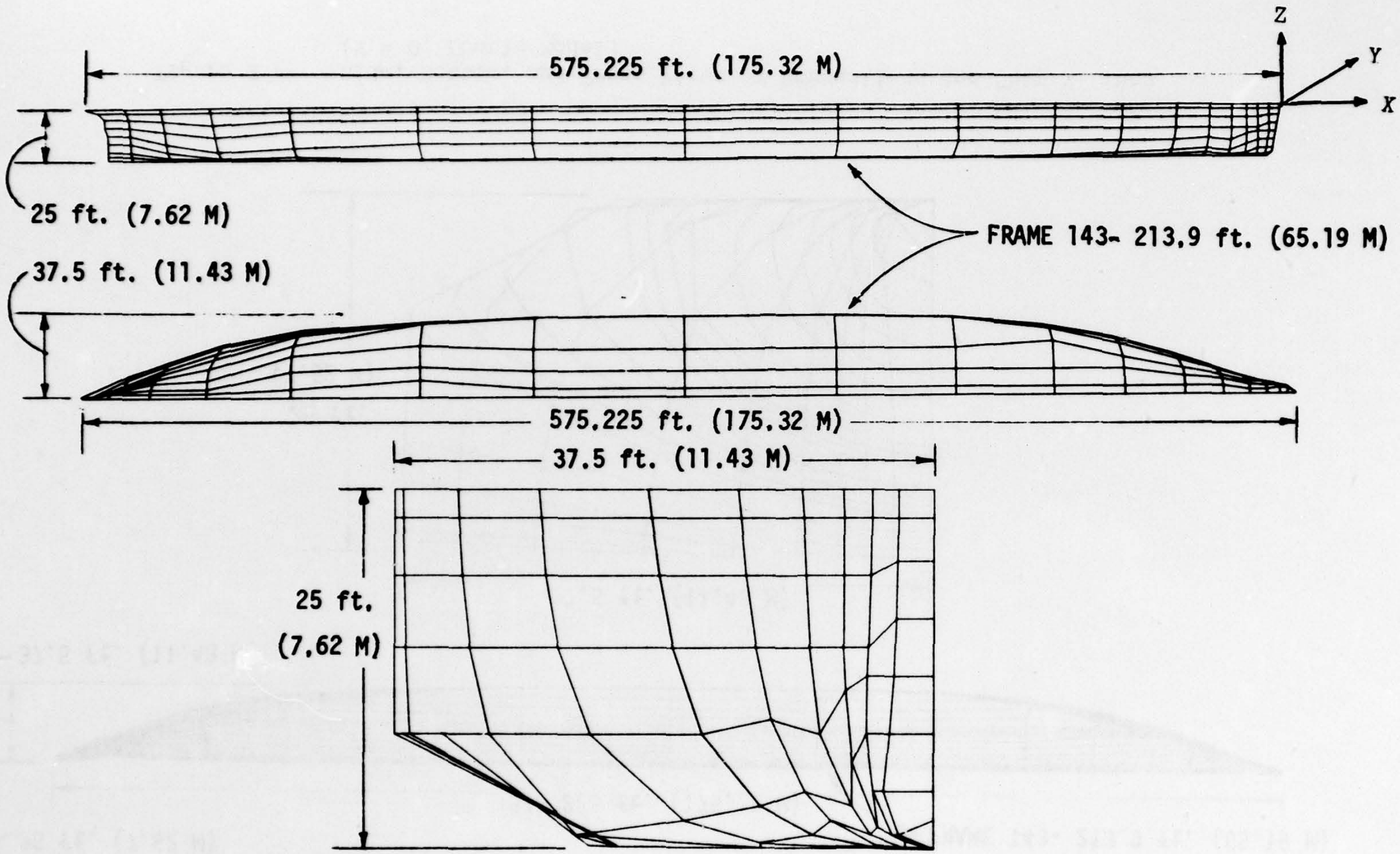

Figure 1 - Side, Bottom, and Front Views of Ship Lines

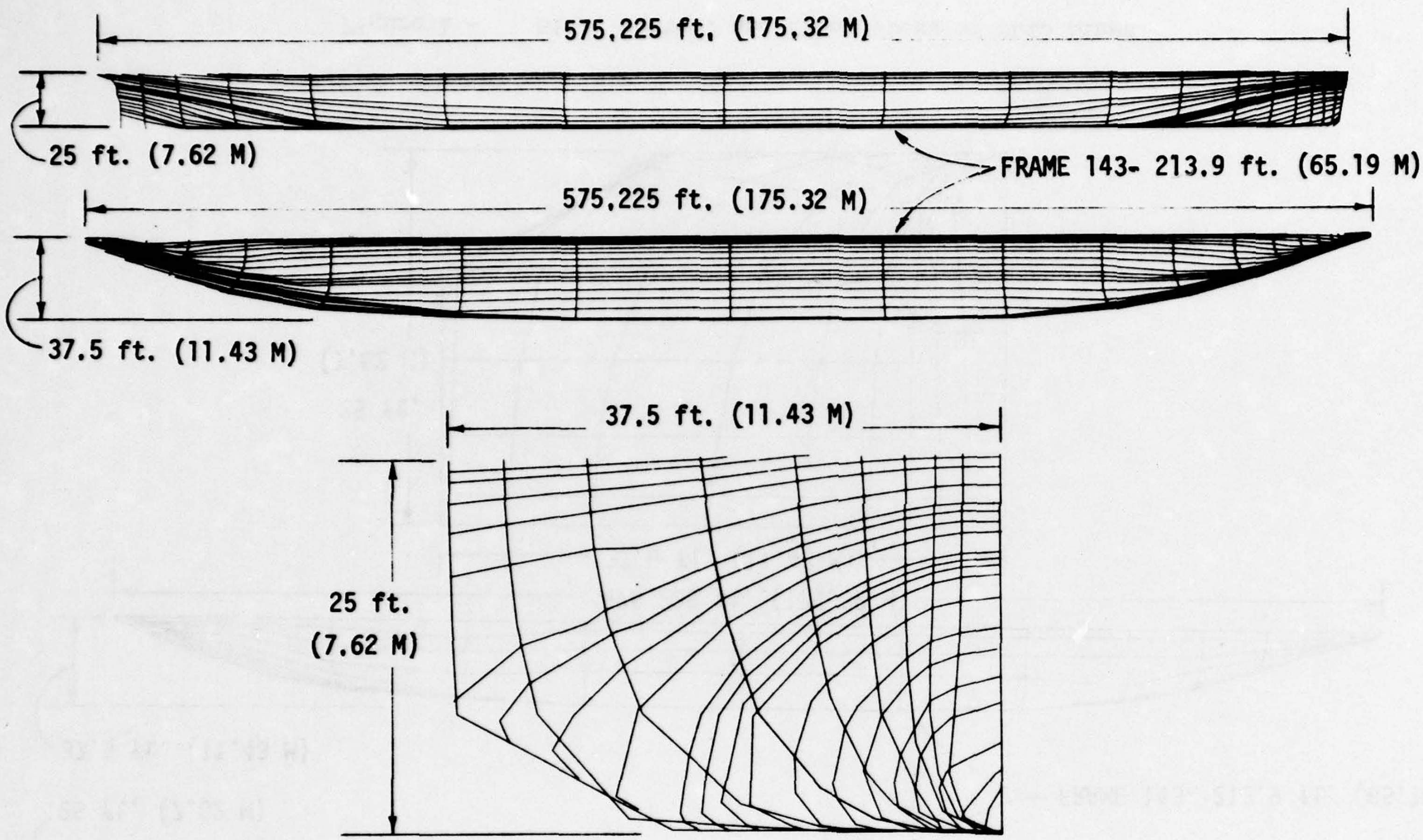

Figure 2 - Side, Bottom, and Front Views of Streamlines and Ship N-Lines (V = 0, Double Model)

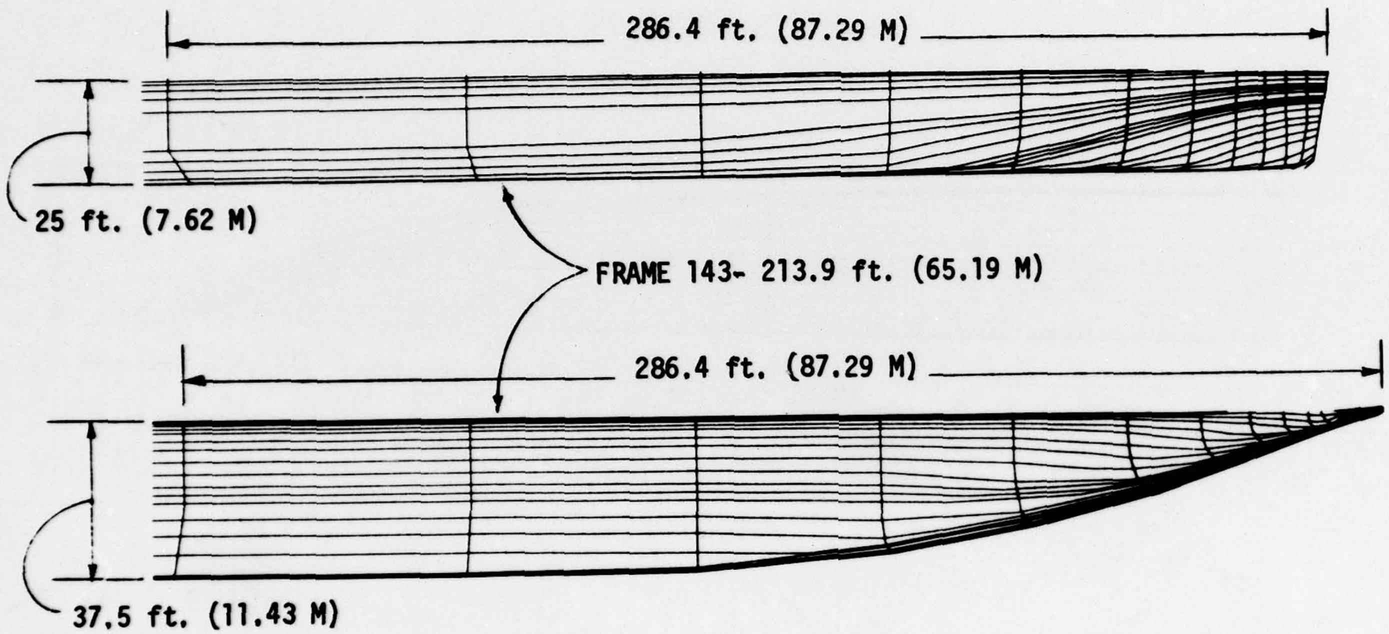

Figure 3 - Side and Bottom Views of Forward Half of Streamlines and Ship N-Lines (V = 0, Double Model)

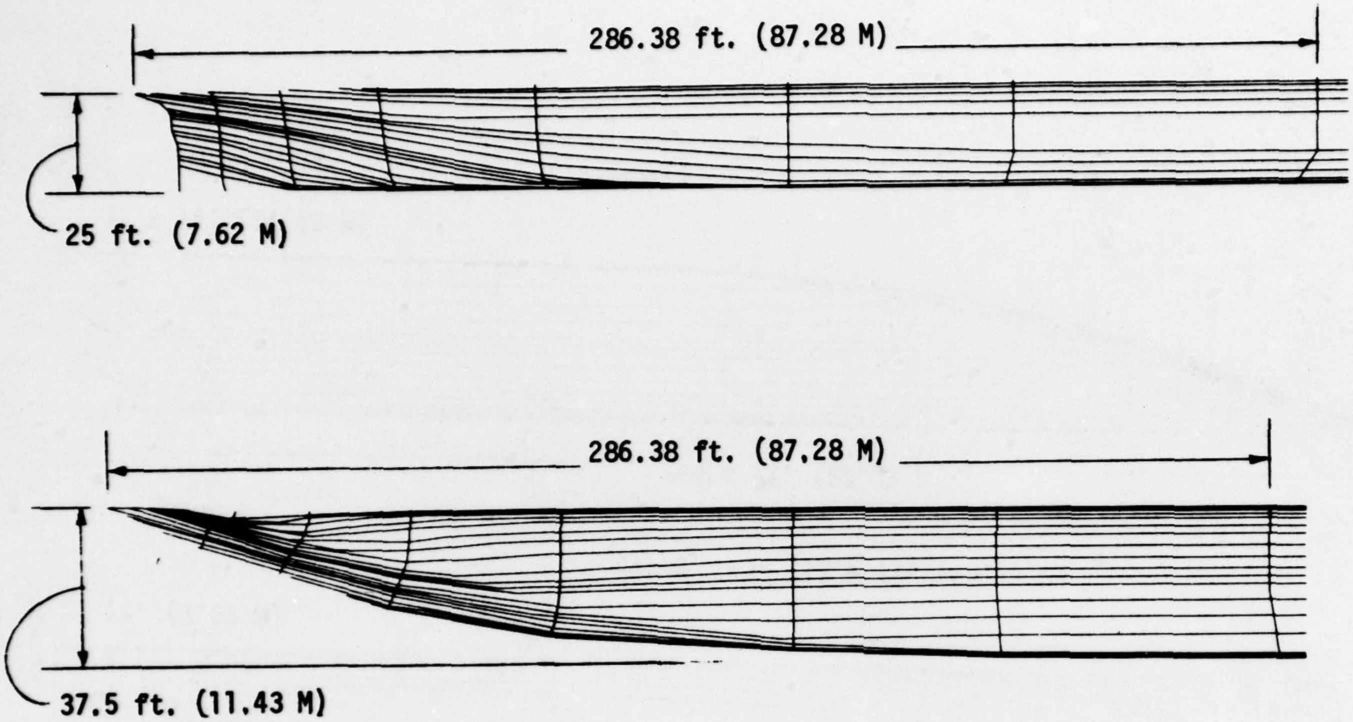

Figure 4 - Side and Bottom Views of Rear Half of Streamlines and Ship N-Lines (V = 0, Double Model)

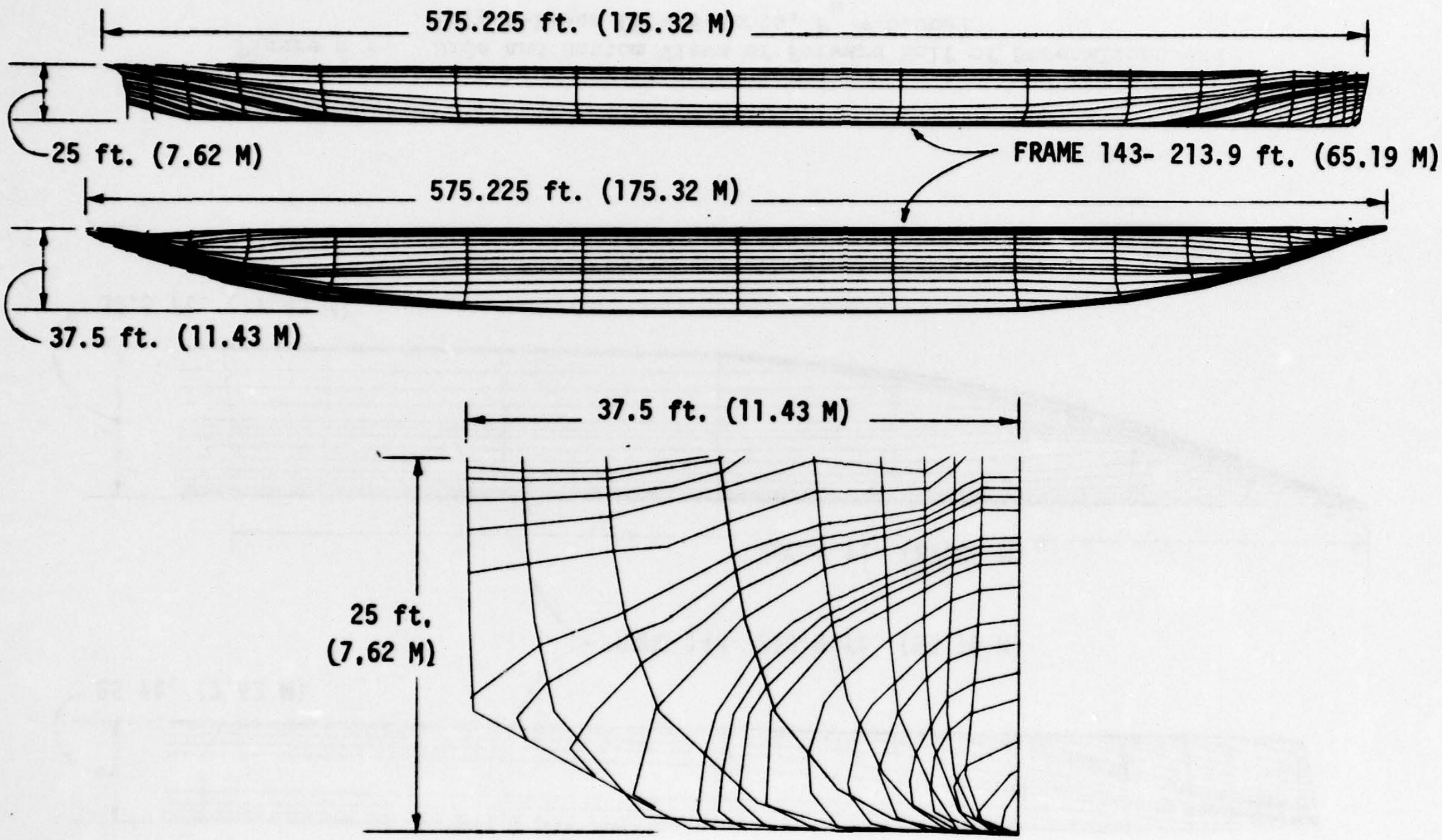

Figure 5 Side, Bottom, and Front Views of Streamlines and Ship N-Lines (V = 5 Knots, F_n = 0.062)

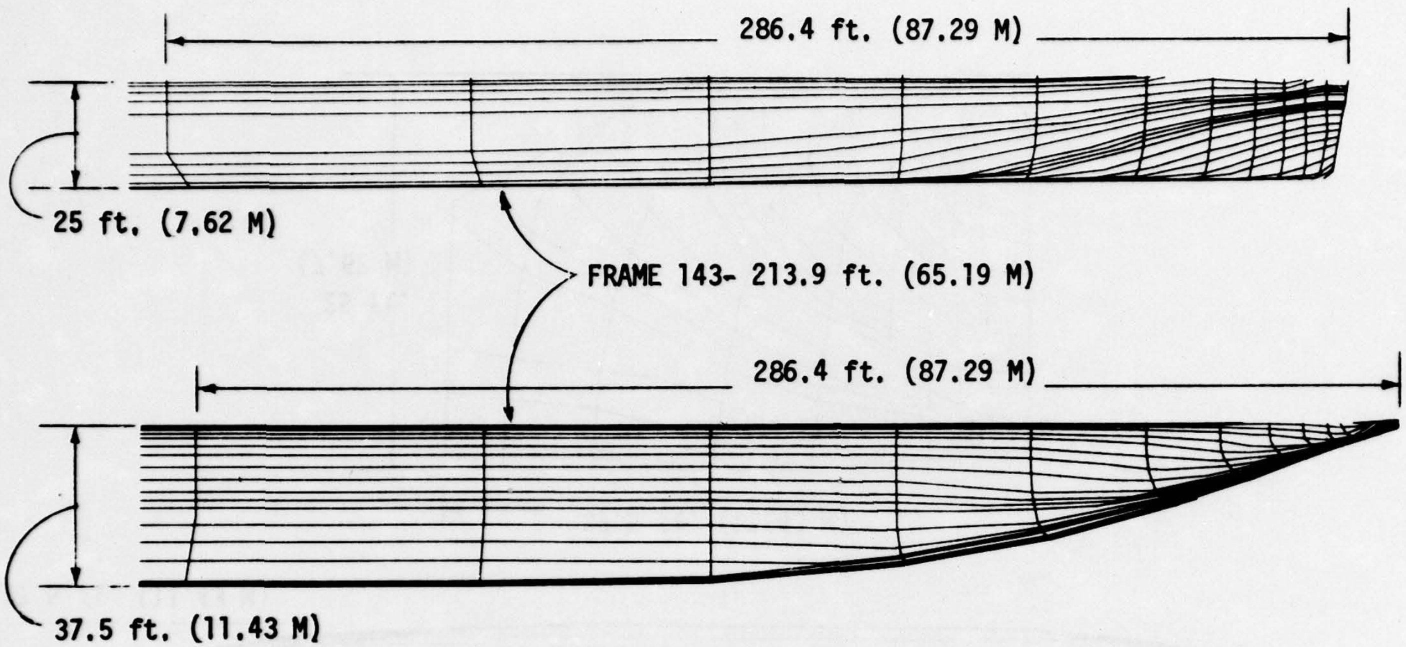

Figure 6 - Side and Bottom Views of Forward Half of Streamlines and Ship N-Lines (V = 5 Knots, F_n = 0.062)

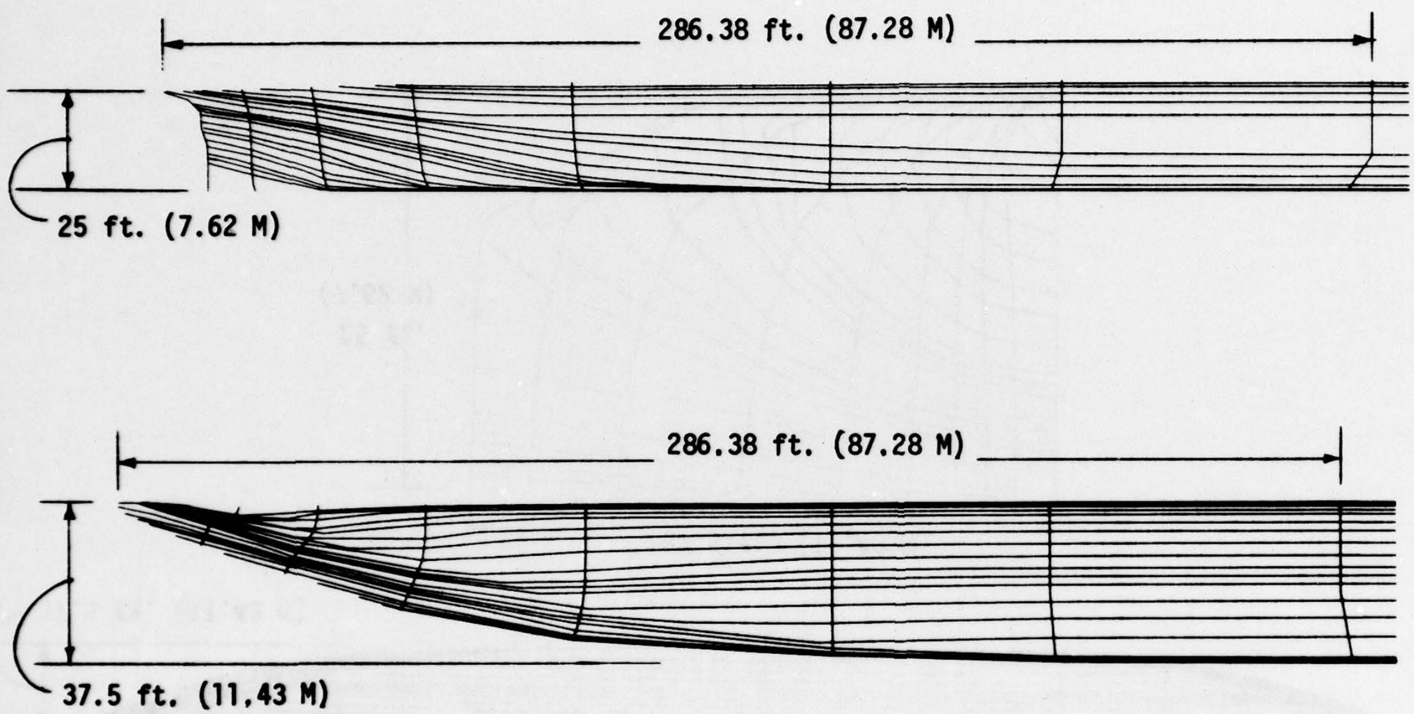

Figure 7 - Side and Bottom Views of Rear Half of Streamlines and Ship N-Lines (V = 5 Knots, F_n = 0.062)

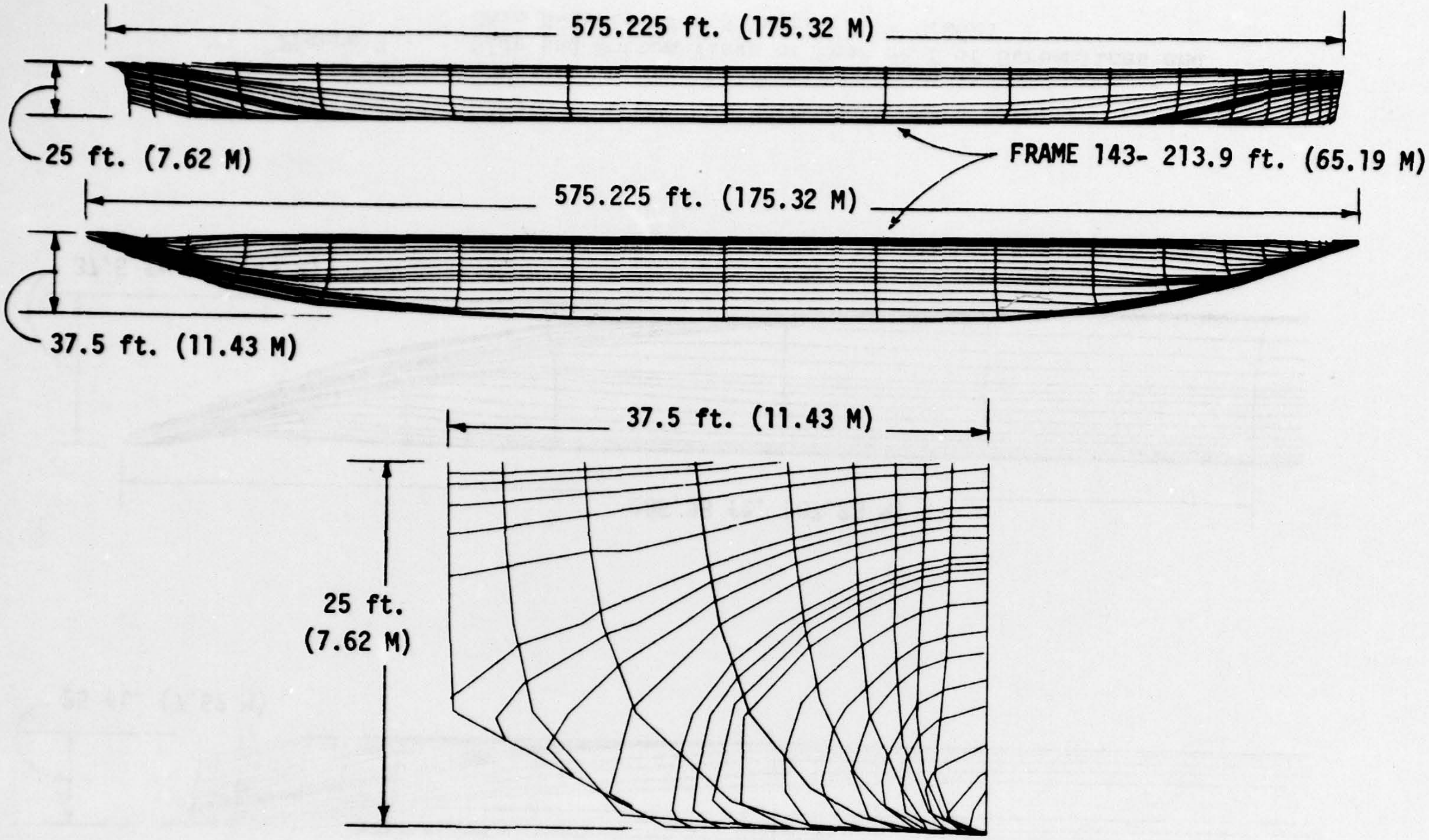

Figure 8 - Side, Bottom, and Front Views of Streamlines and Ship N-Lines (V = 10 Knots, F_n = 0.124)

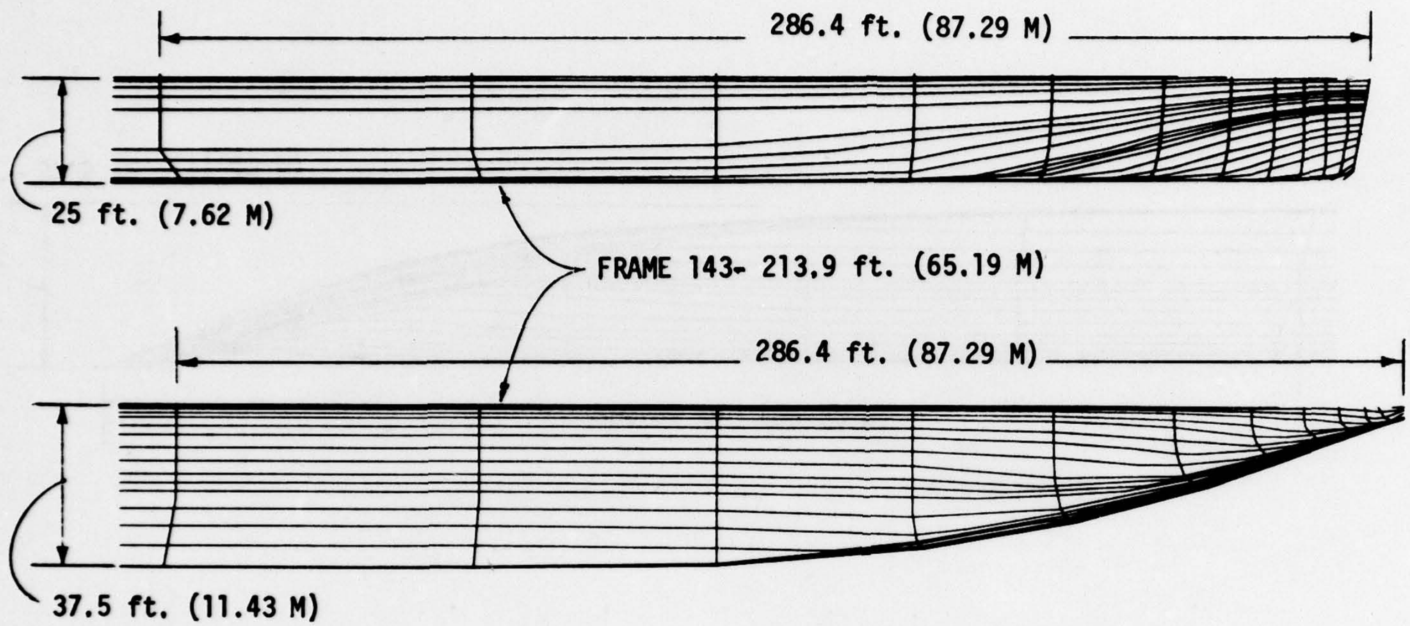

Figure 9 - Side and Bottom Views of Forward Half of Streamlines and Ship N-Lines (V = 10 Knots, F_n = 0.124)

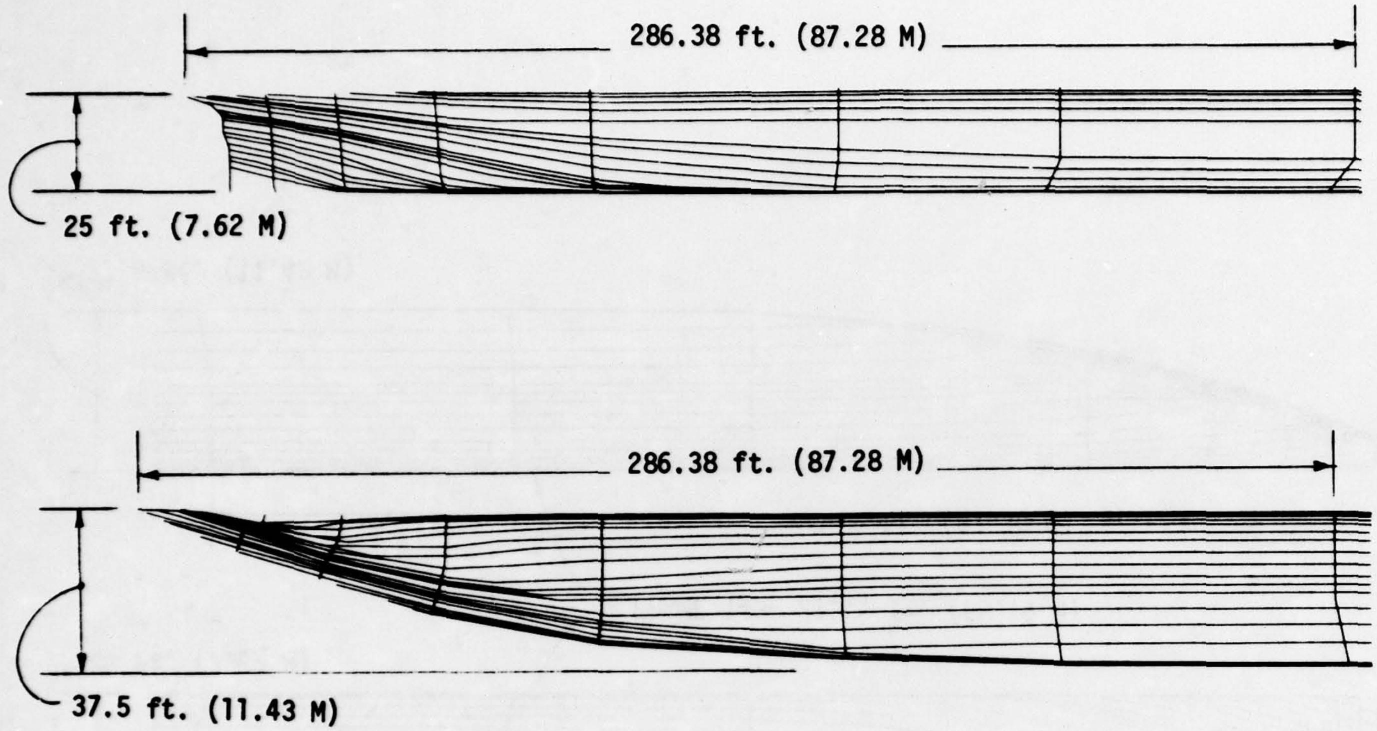

Figure 10 - Side and Bottom Views of Rear Half of Streamlines and Ship N-Lines (V = 10 Knots, F_n = 0.124)

TABLE 1

CLOSEST APPROACH OF STREAMLINES (IN FT) TO ACTUAL FREE SURFACE IN BOW REGION

	Streamline at Frame 143			V in Knots		
No.	X = -213.9 Ft(-65.19M)	0	5	10	20	30
1	(Y=-0.1, Z=-25.0)	-25.0	-25.0	-25.0	-25.0	-25.0
2	(Y=-0.2, Z=-25.0)	-22.0	-22.4	-24.4	-25.0	-25.0
3	(Y=-0.5, Z=-25.0)	-20.8	-21.2	-23.1	-25.0	-25.0
4	(Y=-1.0, Z=-25.0)	-19.0	-19.4	-21.2	-24.9	-24.9
5	(Y=-2.0, Z=-25.0)	-16.4	-16.7	-18.4	-22.4	-23.1
6	(Y=-3.0, Z=-24.9)	-14.6	-15.0	-16.7	-20.9	-21.8
7	(Y=-5.0, Z=-24.9)	-12.8	-13.2	-14.8	-19.3	-20.4
8	(Y=-7.0, Z=-24.9)	-11.4	-11.7	-13.0	-17.7	-19.5
9	(Y=-10.0,Z=-24.9)	-9.4	-9.7	-10.7	-15.8	-18.0
10	(Y=-13.0,Z=-24.9)	-7.9	-8.1	-9.1	-13.9	-17.2
11	(Y=-16.0,Z=-24.9)	-7.3	-7.5	-8.2	-13.4	-16.2
12	(Y=-18.0,Z=-24.9)	-6.8	-7.0	-7.6	-12.9	-15.5
13	(Y=-20.0,Z=-24.8)	-6.4	-6.6	-7.2	-12.0	*
14	(Y=-24.0,Z=-23.8)	-5.1	-5.3	-5.4	*	
15	(Y=-28.0,Z=-21.8)	-4.4	-4.5	-4.7		
16	(Y=-32.5,Z=-19.5)	-3.7	-3.8	-4.2		
17	(Y=-37.0,Z=-17.0)	-3.2	-3.3	-3.5		
18	(Y=-37.5,Z=-8.0)	-2.0	-2.0	*		
19	(Y=-37.5,Z=-5.0)	-0.8	-0.7			
20	(Y=-37.5,Z=-3.0)	-0.2	*			
21	(Y=-37.5,Z=-1.5)	*				
22	(Y=-37.5,Z=-0.75)					

*Z=0 is reached aft of stem, |closest approach| ≤ maximum bow wave elevation shown in Table 2.

TABLE 2

SHAPE OF BOW WAVE

WAVE ELEVATION Z (Ft)

X (Ft)	V = 0	V = 5	V = 10	V = 20	V = 30
0.	0.	0.38	2.40	5.18	4.24
-10.	0.	0.24	1.68	7.88	7.60
-20.	0.	0.19	0.18	9.47	12.53
-30.	0.	0.14	0.39	8.04	16.11
-40.	0.	0.09	0.51	5.45	15.38
-50.	0.	0.05	0.44	3.20	13.06
-60.	0.	-0.01	0.15	1.82	10.99
-70.	0.	-0.02	-0.13	0.44	8.92
-80.	0.	-0.04	-0.32	-0.69	6.76
-90.	0.	-0.07	-0.40	-1.80	4.61
-100.	0.	-0.09	-0.48	-2.96	2.46

TABLE 3

LOCATIONS OF STREAMLINES AT X=-155 (-47.24) AND -244 FEET (-74.37M)
FOR V = 0, 5, AND 10 KNOTS *

Streamline at Frame 143 (in ft)

	X = -213.9 Ft (-65.19M)	X = -155 Ft (-47.24M)	X = -244 Ft (-74.37M)
1.	(Y=-0.1, Z=-25.0)	(-0.1, -25.0)	(-0.1, -25.0)
2.	(Y=-0.2, Z=-25.0)	(-0.2, -25.0)	(-0.2, -25.0)
3.	(Y=-0.5, Z=-25.0)	(-0.5, -25.0)	(-0.5, -25.0)
4.	(Y=-1.0, Z=-25.0)	(-1.0, -25.0)	(-1.0, -25.0)
5.	(Y=-2.0, Z=-25.0)	(-2.0, -25.0)	(-2.0, -25.0)
6.	(Y=-3.0, Z=-24.9)	(-3.0, -24.9)	(-3.0, -24.9)
7.	(Y=-5.0, Z=-24.9)	(-5.1, -24.9)	(-5.0, -24.9)
8.	(Y=-7.0, Z=-24.9)	(-7.1, -24.9)	(-7.0, -24.9)
9.	(Y=-10.0,Z=-24.9)	(-10.1,-24.9)	(-10.0,-24.9)
10.	(Y=-13.0,Z=-24.9)	(-13.2,-24.9)	(-13.0,-24.9)
11.	(Y=-16.0,Z=-24.9)	(-16.3,-24.8)	(-16.0.-24.9)
12.	(Y=-18.0,Z=-24.9)	(-18.3,-24.8)	(-18.0,-24.9)
13.	(Y=-20.0,Z=-24.8)	(-20.3,-24.8)	(-20.0,-24.8)
14.	(Y=-24.0,Z=-23.8)	(-24.4,-23.5)	(-24.1,-23.8)
15.	(Y=-28.0,Z=-21.8)	(-28.5,-21.1)	(-28.1,-21.8)
16.	(Y=-32.5,Z=-19.5)	(-33.0,-18.6)	(-32.5,-19.4)
17.	(Y=-37.0,Z=-17.0)	(-36.0,-15.4)	(-37.4,-17.0)
18.	(Y=-37.5, Z=-8.0)	(-36.2, -7.7)	(-37.5, -8.0)
19.	(Y=-37.5, Z=-5.0)	(-36.3, -4.8)	(-37.5, -5.0)
20.	(Y=-37.5, Z=-3.0)	(-36.3, -2.9)	(-37.5, -3.0)
21.	(Y=-37.5, Z=-1.5)	(-36.3, -1.4)	(-37.5, -1.5)
22.	(Y=-37.5,Z=-0.75)	(-36.3,-0.73)	(-37.5,-0.75)

* The computed differences between locations of streamlines at 0, 5 and 10 knots were less than 0.1 feet (0.03).

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